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Coupling of groundwater, river flow and rainfall in an upland floodplain

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Upland floodplains provide an important function in regulating river flows and controlling the coupling of hillslope runoff with rivers. To investigate the responses of floodplain groundwater to river flows and rainfall events, a small floodplain in an upland area of the River Tweed catchment, Scotland, was characterised using geophysics, 3D geological mapping and hydrogeological testing; and monitoring undertaken from September 2011 to February 2013 of: groundwater levels in five pairs of piezometers; river stage and flow at the upstream and downstream limits of the study site; soil moisture on the adjacent hillslope; and meteorological parameters. Periodical groundwater chemistry and residence data were also collected.

The floodplain aquifer is permeable throughout but partially stratified, comprising dominantly alluvial and glaciofluvial sandy gravels between 8 and 15m interspersed with thin, intermittent layers of low permeability silts, clays and peats. Overlying the gravel aquifer is a partial thin cover of low permeability alluvial silts, and it is underlain dominantly by low permeability glaciolacustrine silts and clays. High permeability solifluction deposits mantle much of the adjacent hillslope and provide a rapid connection to the floodplain aquifer.

The unusually wet year of 2012 provides a good example of how a temperate upland floodplain responds to consistently high rainfall. Statistical analysis and graphical interpretation of groundwater level, rainfall, soil moisture and river stage demonstrates that: 1) dominant groundwater flow within the floodplain is in the same direction as the river, from up-valley to down-valley; 2) soil moisture in the hillslope is strongly correlated with local rainfall, but groundwater across much of the floodplain is more strongly influenced by river stage; except 3) groundwater near the edge of floodplain, which responds more slowly to local rainfall and river stage changes ; and 4) subsurface flow from the hillslope to the floodplain occurs during high rainfall events.

A detailed investigation of three flood events, when the river rose above bank level and flooded adjacent fields and groundwater became artesian in parts of the floodplain, suggests that antecedent moisture conditions can partly explain the differences in groundwater response during different flood events, where high intensity or long duration rainfall can cause saturated soil conditions, reducing soil water storage capacity and hence promoting flood conditions. A conceptual model based on field data of groundwater flow after storm events during antecedent unsaturated and saturated soil conditions is presented.